Subaperture stitching interferometry for large aspheric optics

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Scott Antonille – NASA Goddard

Outline

- Motivation
- Subaperture stitching interferometer (SSI®): background
- Aspheric Optics: success of the SSI-A™
  - Non-null interferometric testing
  - Measurement results
- Large Optics: scaling the SSI®
- Conclusions

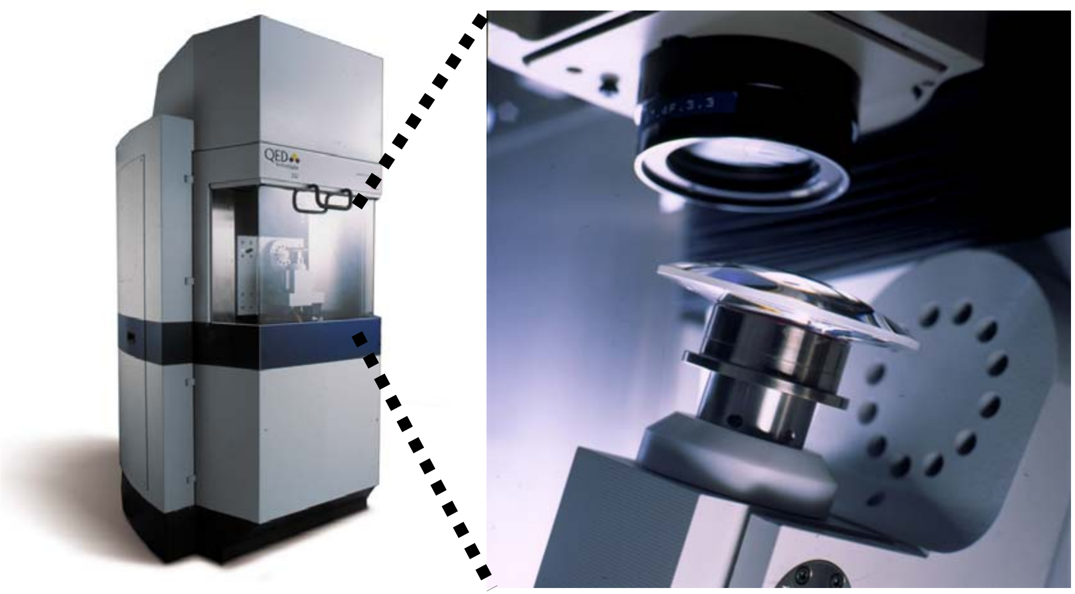
Motivation

"If you can't measure it, you can't make it"

- Corollary: the quality of your measurement limits the quality of optical surface you can make
- And therefore we want our metrology to be:
  - Full aperture, for deterministic correction of the whole surface
  - Accurate, to achieve tighter optical specifications
  - High resolution, to correct edges and other small features
  - Flexible, to minimize custom tooling and lead time
- Solve needs for Aspheric Metrology
  - Increase aspheric departure measurement capability of standard Fizeau interferometer with no auxiliary nulling optics
  - Obtain accuracy comparable to CGH null
  - Obtain high lateral resolution
  - Obtain quality measurement with ordinary skill
- *Subaperture stitching can address all these needs*

Subaperture Stitching Interferometer (SSI®)

- Precision six axis machine
  - Engineered in cooperation with Schneider Opticmachines
- Standard Zygo® 4” or 6” interferometer
- QED control software: automation + advanced algorithms



SSI advantages

- Cost-effective measurement of larger apertures
- Automatic, inline calibration of systematic error
- Increased lateral resolution
- Measures mild aspheres *without dedicated nulls*!

SSI measurement process

Specify surface to test

Select transmission sphere and define lattice

Locate central null

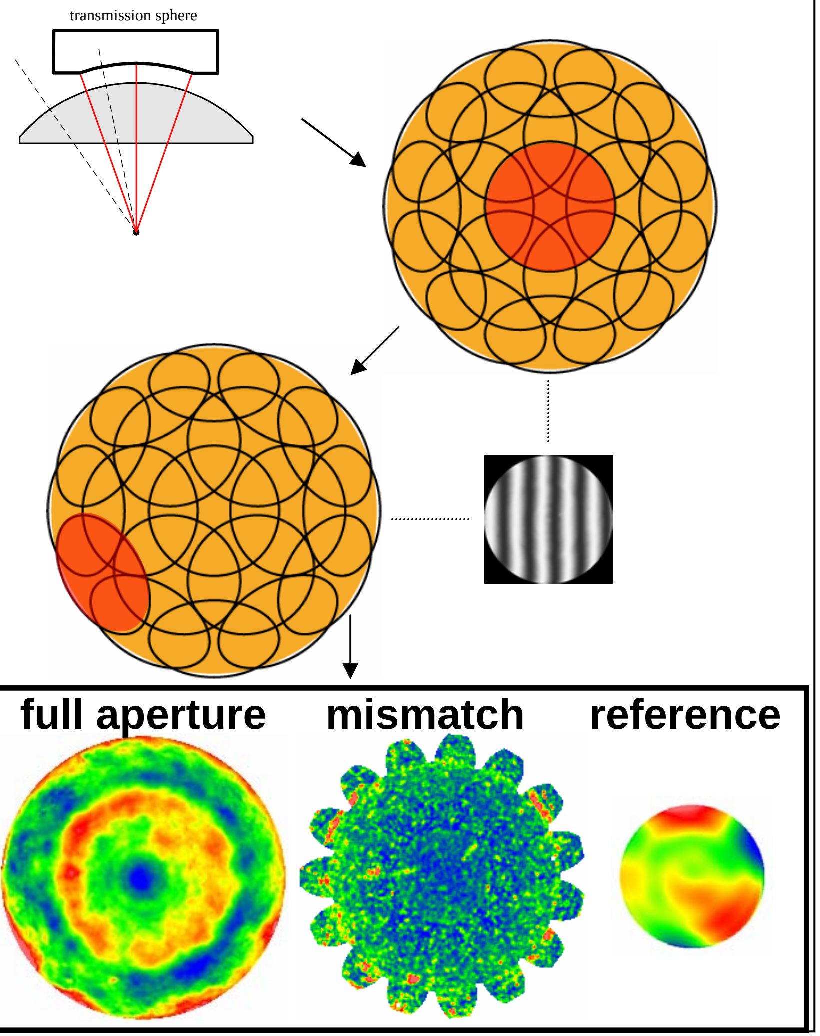
Move to lattice position

Auto-null

Measure

Stitch

★★ Fully automated block ★★



Overview of stitching benefits

- Increased lateral dynamic range
  - Increased lateral range (large clear and/or numerical aperture)
  - Can improve lateral resolution (data density)

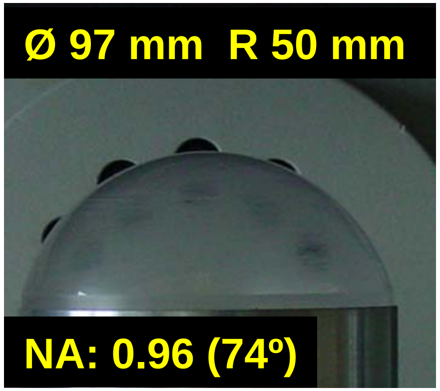
- Superior accuracy
  - Automatic computation or measurement of reference wave
  - Calculation of mapping errors (pixel scale, distortion)
  - *Reduced cavity lengths for concave mirrors*

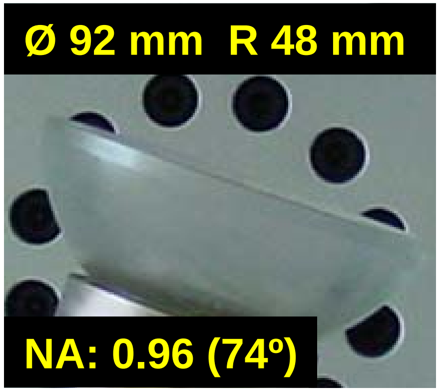
- Avoid dedicated nulls for asphere testing
  - Extended non-null test capability

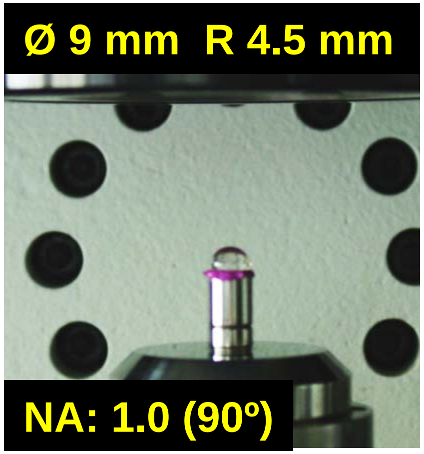
- These benefits can also apply to mid-spatial frequency measurements (in addition to surface form)

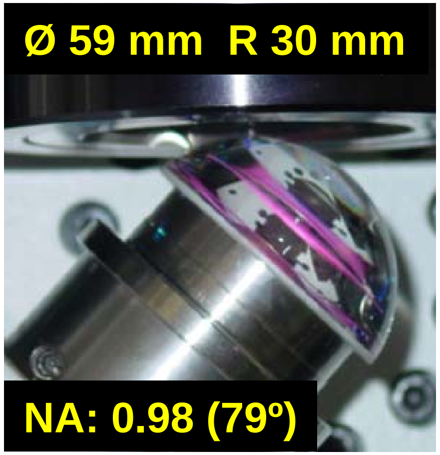
The SSI measures parts that a 6” interferometer cannot test

Large numerical aperture

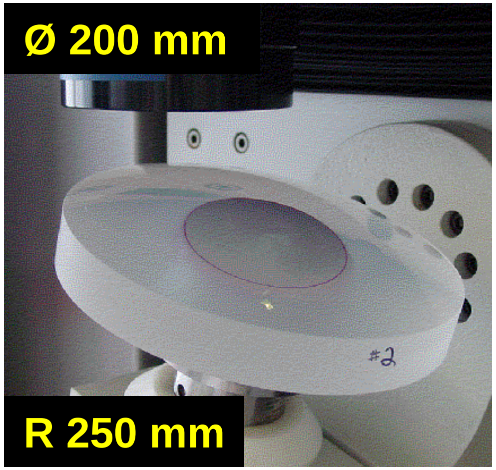


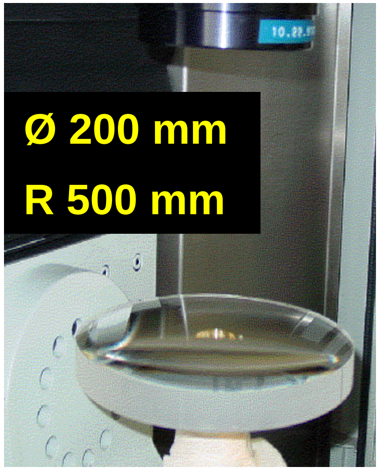


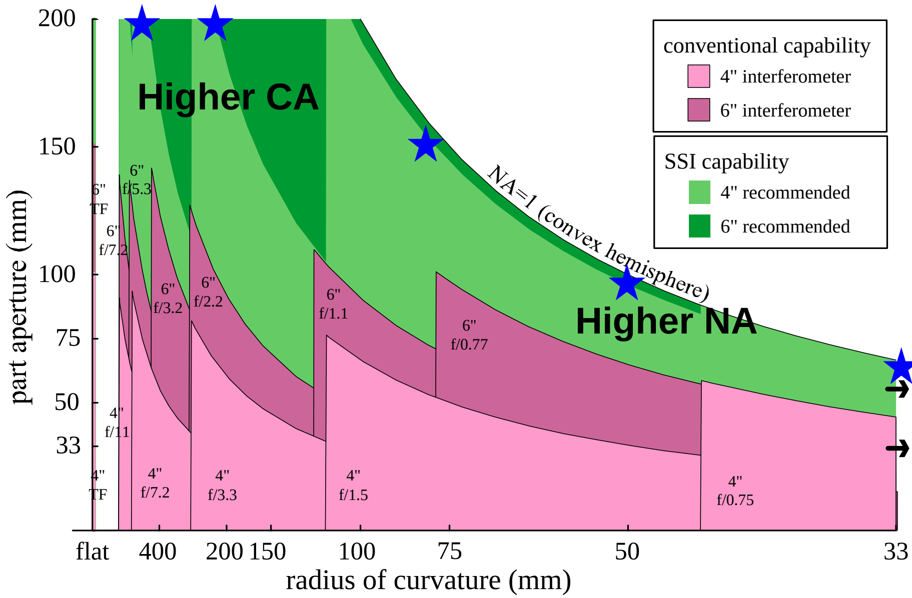




Large clear aperture





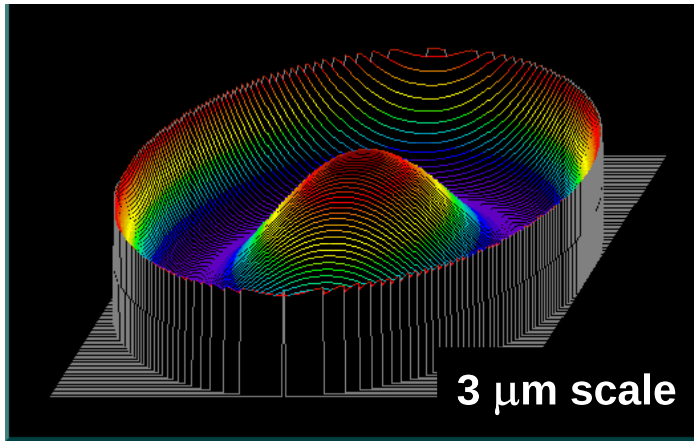


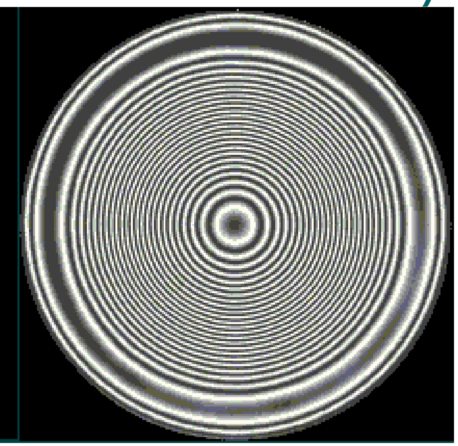
Non-null test example

- Very mild hyperbola: 3.1 μm departure

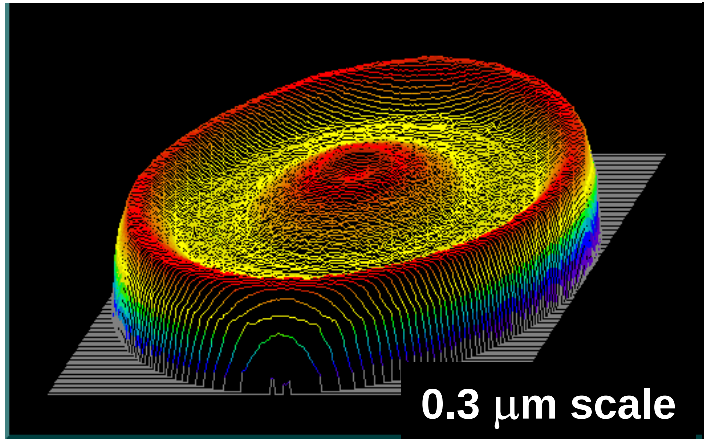
(close to the slope limit of a standard interferometer)

Non-null measurement (spherical reference – measurement is deviation from best-fit sphere, *not* asphere)





Deviation from asphere (nominal aspheric prescription subtracted from the measurement)



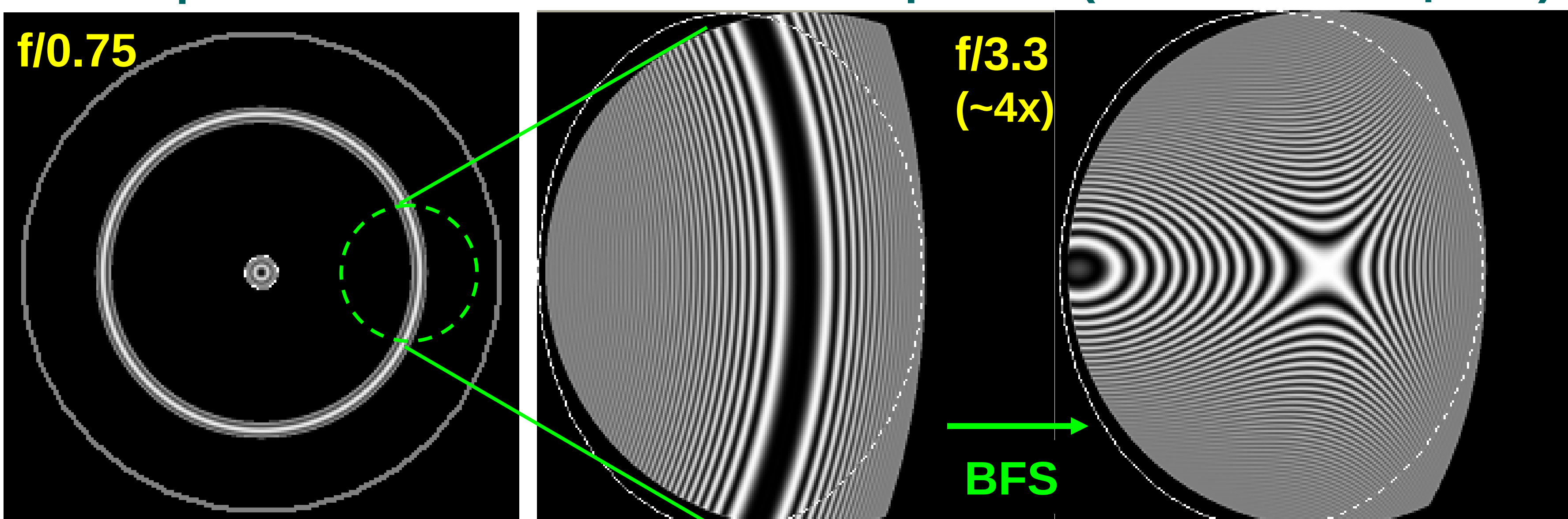
Non-null test issues and solutions

- Fringe resolution
  - Dense fringes cannot be resolved, limiting the amount of aspheric departure measurable in a non-null test
  - Use slower transmission sphere (higher magnification) + stitch
- Retrace error
  - Many fringes in view induce systematic error
  - Automatically model and compensate with stitching
- Remove nominal shape
  - More sensitive to alignment, lateral calibration, and distortion
  - Precise motion + automatic computation + compensation

Increasing measurable aspheric departure: how does it work?

- Magnification is key for resolving dense fringes
  - Simulated fringes for ~50 μm aspheric departure
  - Most of the data is unresolvable in the full aperture

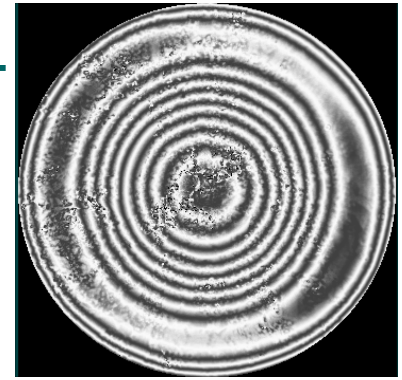
Full aperture **67% zone subaperture (& local best-fit sphere)**



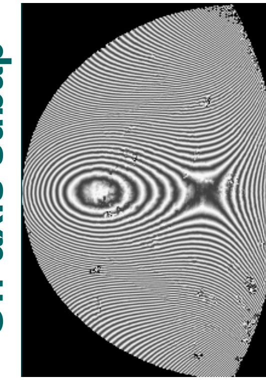
SSI-A example #1

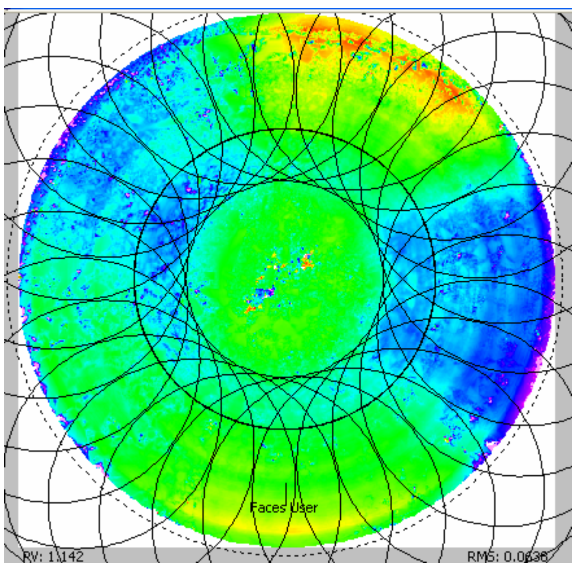
- Radius ~ -310 mm,
- Aperture 110 mm,
- ~20 µm departure
- ellipsoid

Central subap



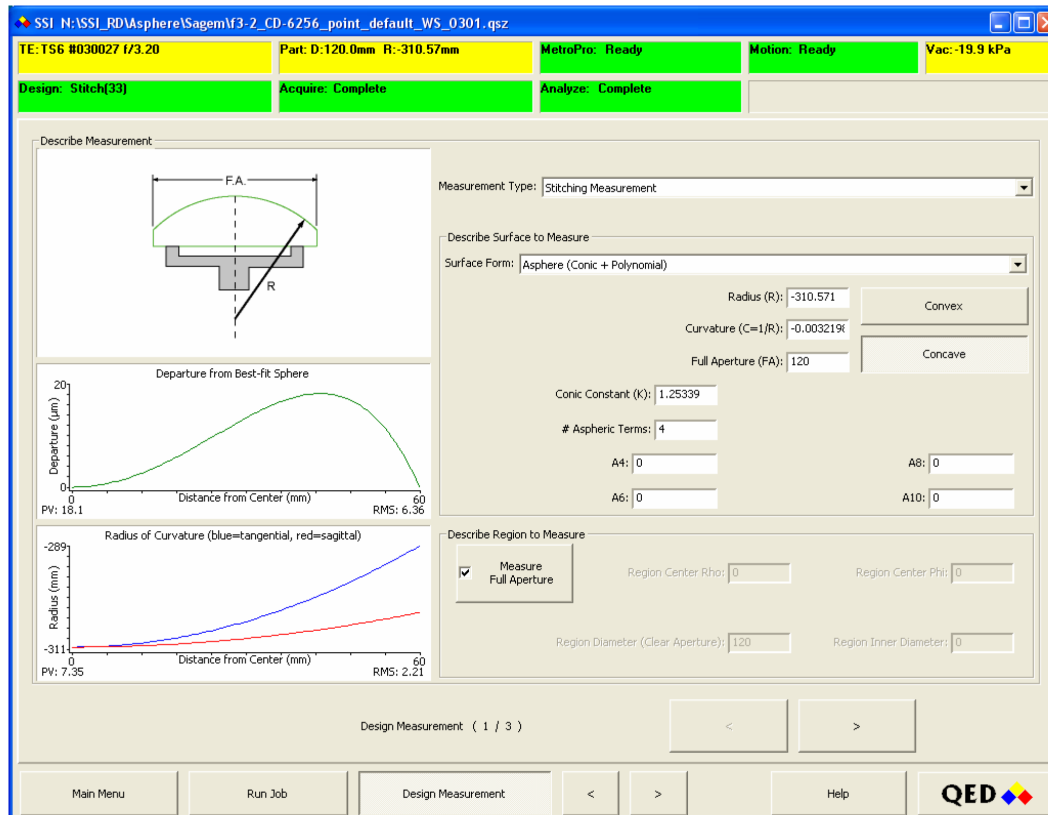
Off-axis subap





Stitch map (+lattice)

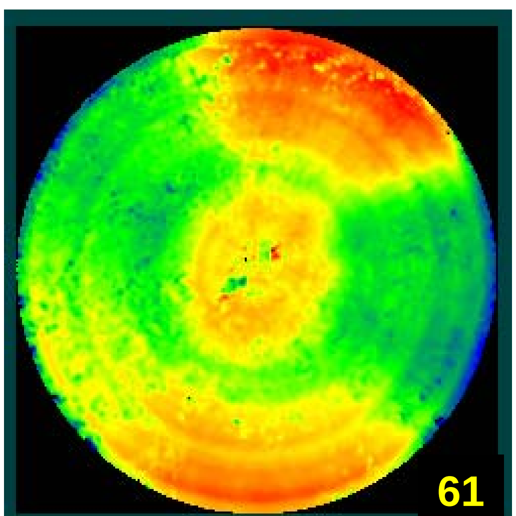
33 subapertures w/ 6” f/3.2



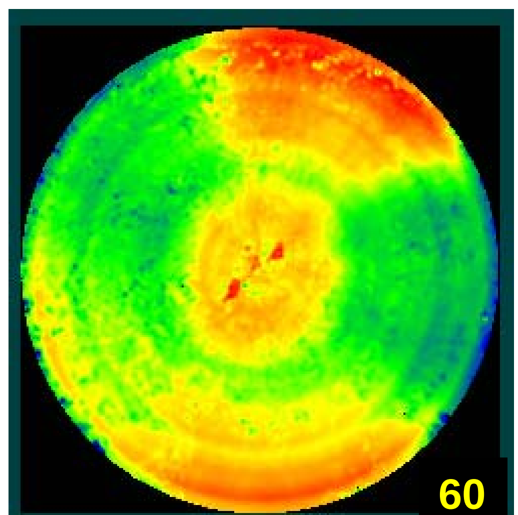
Example #1 performance data

- Results are both repeatable and have good agreement with a CGH cross-test
  - Higher resolution in stitch map
  - SSI auto-calibrates; CGH calibration more difficult

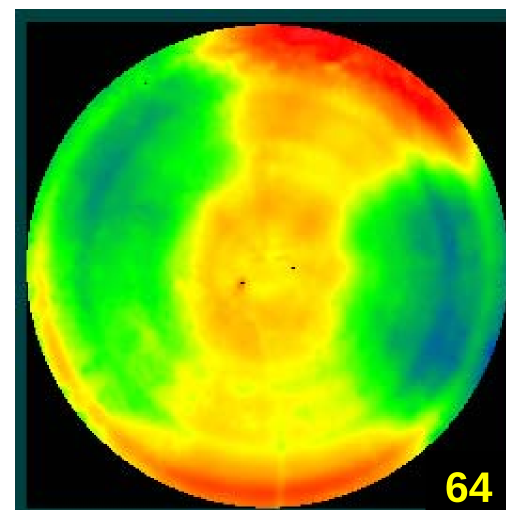
Stitch repeat #1



Stitch repeat #2



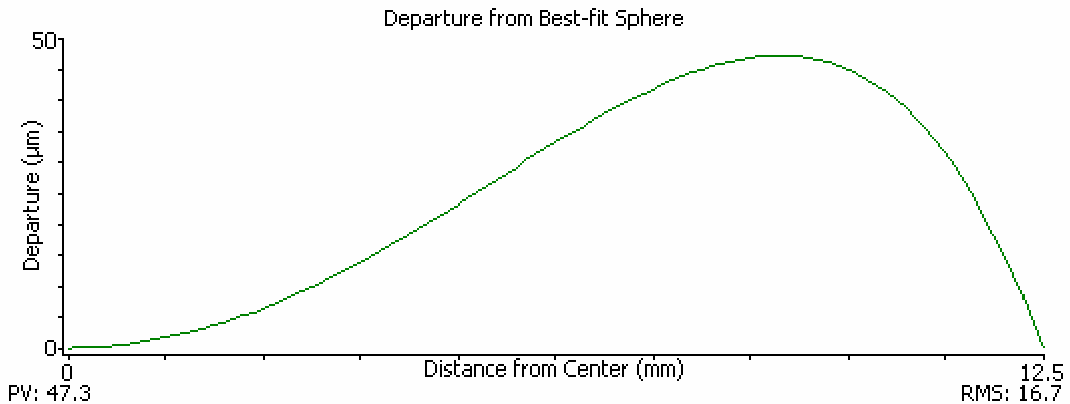
CGH test



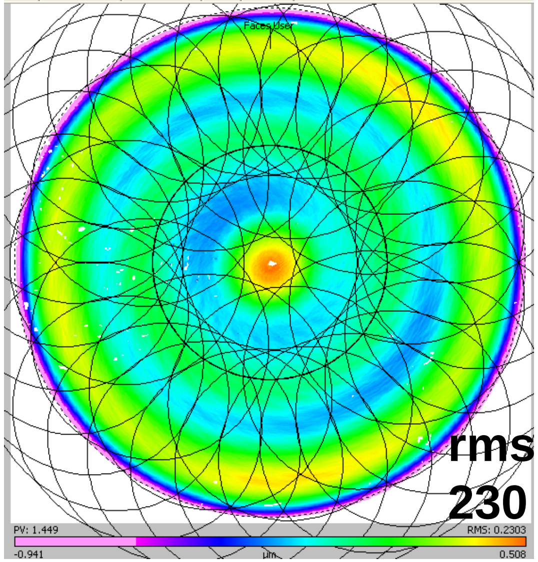
nm rms

SSI-A example #2
(more departure: ~50 μm)

- Radius ~ 22 mm
- Aperture 25 mm
- ***~50 μm departure***

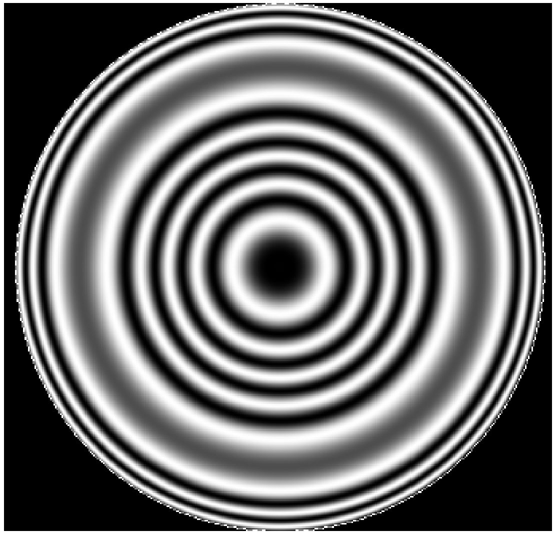


Stitch map (+lattice)

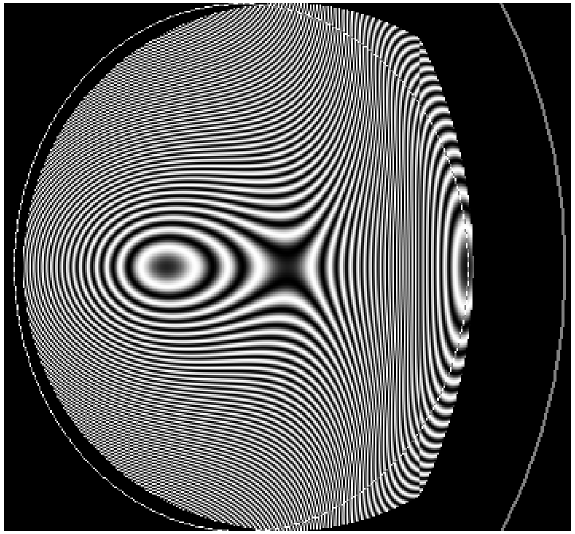


35 subapertures w/ 6" f/2.2

Central subap

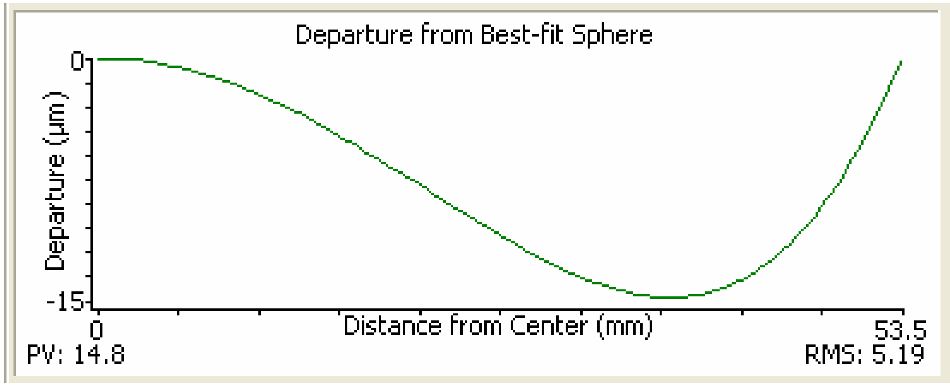


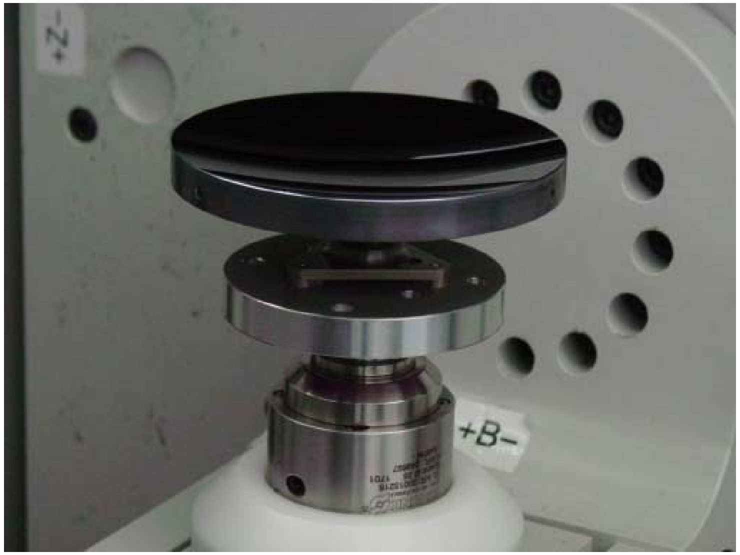
Off-axis subap



SSI-A example #3 (high quality: <5 nm rms)

- Part manufactured by SSG-Tinsley for a NASA SBIR
  - ~100 mm aperture diameter, base radius –226 mm
  - Ellipsoid (conic), with ~12 µm of aspheric departure
  - Lightweighted silicon carbide with silicon cladding
  - Used as a secondary mirror for the PICTURE/SHARPI sounding rocket programs

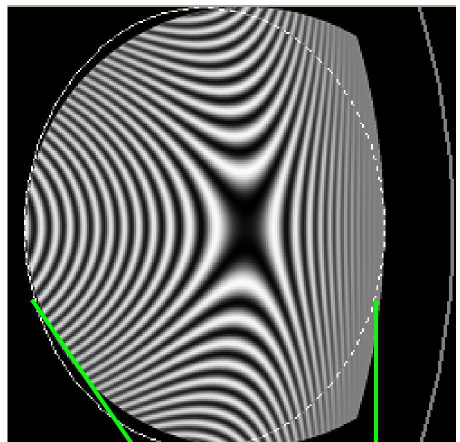


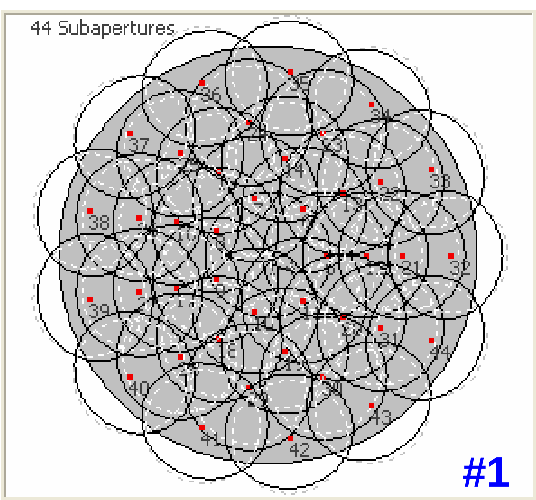


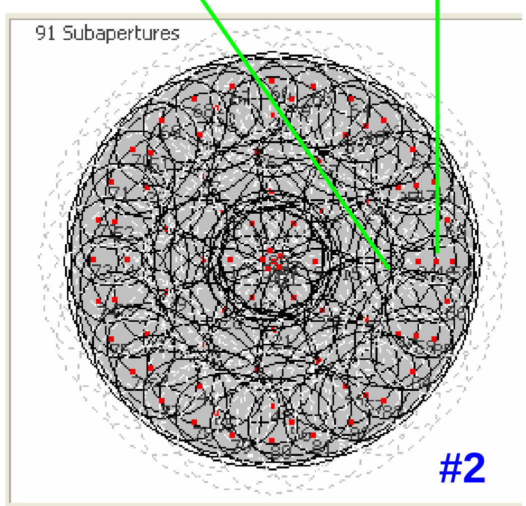
SSI-A^{TM} example 3: test setup

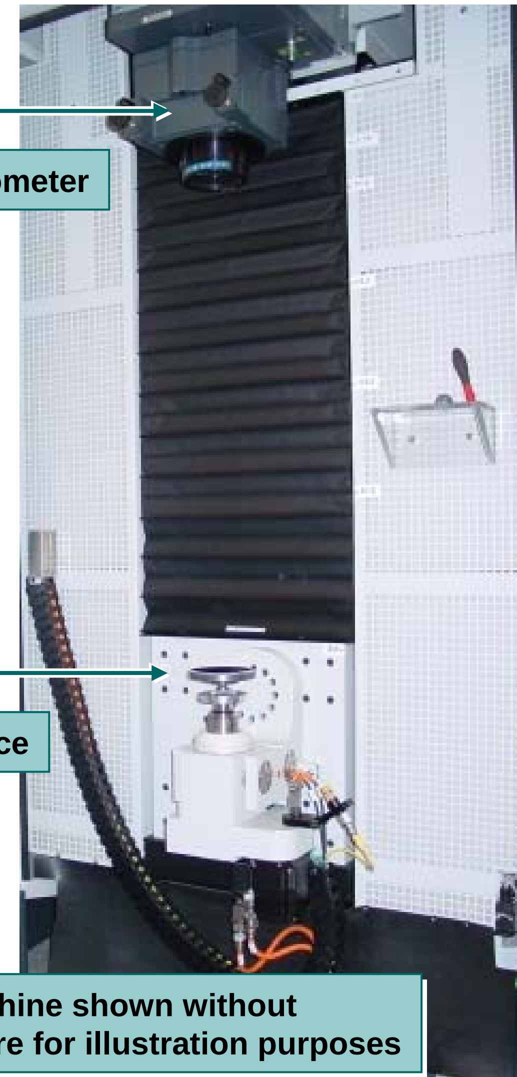
- F/7.2 TS for stitch
  - Lattice #1 balances speed and accuracy
  - Lattice #2 is denser, slightly improving accuracy
- Note: Null test is F/1.5

Subaperture 38 mm off axis



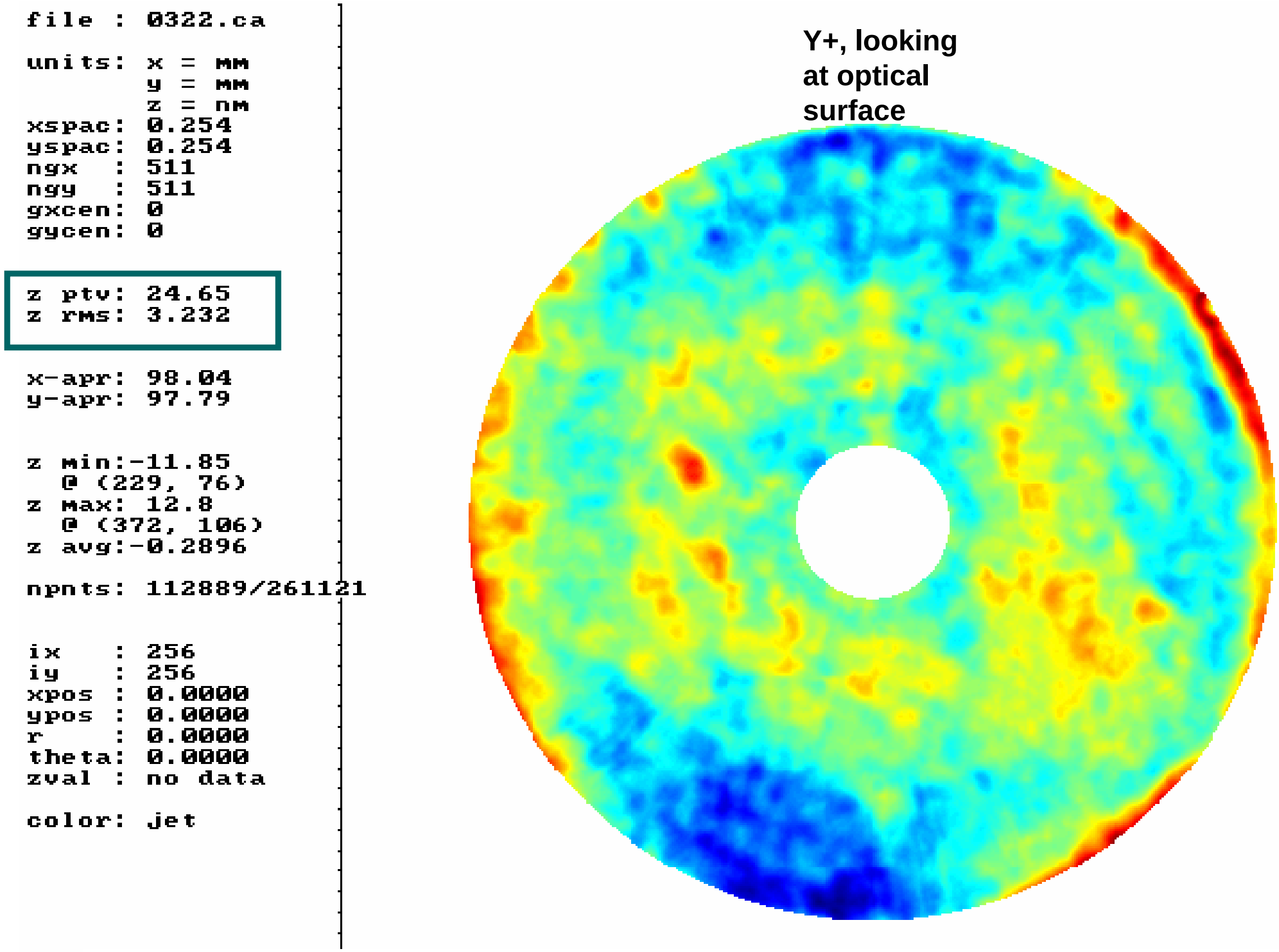


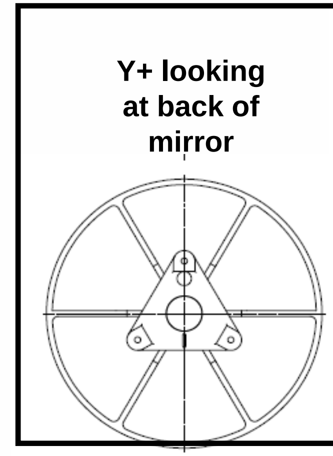


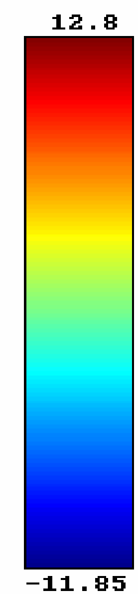


L3-SSG-Tinsley Si-clad SiC EUV M2

Clear Aperture 3.864” Diameter







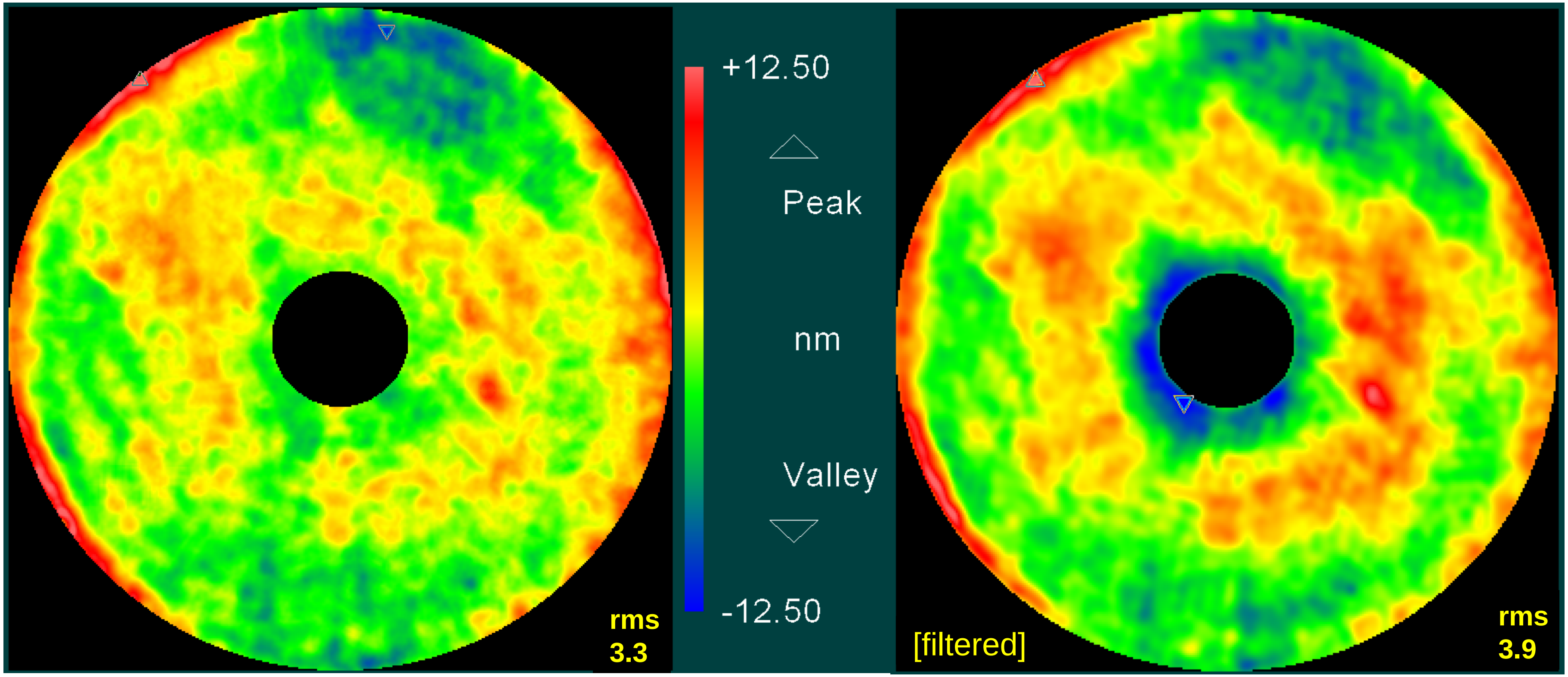
(Manufacturer’s conic null test over the clear aperture)
Data courtesy of Jay Schwartz.

L3 communications SSG-Tinsley

Example #3 performance data

- Good agreement with existing null test
  - Stitched measurement resolves finer structure

Null test (conic w/ retrosphere) **SSI-A measurement**

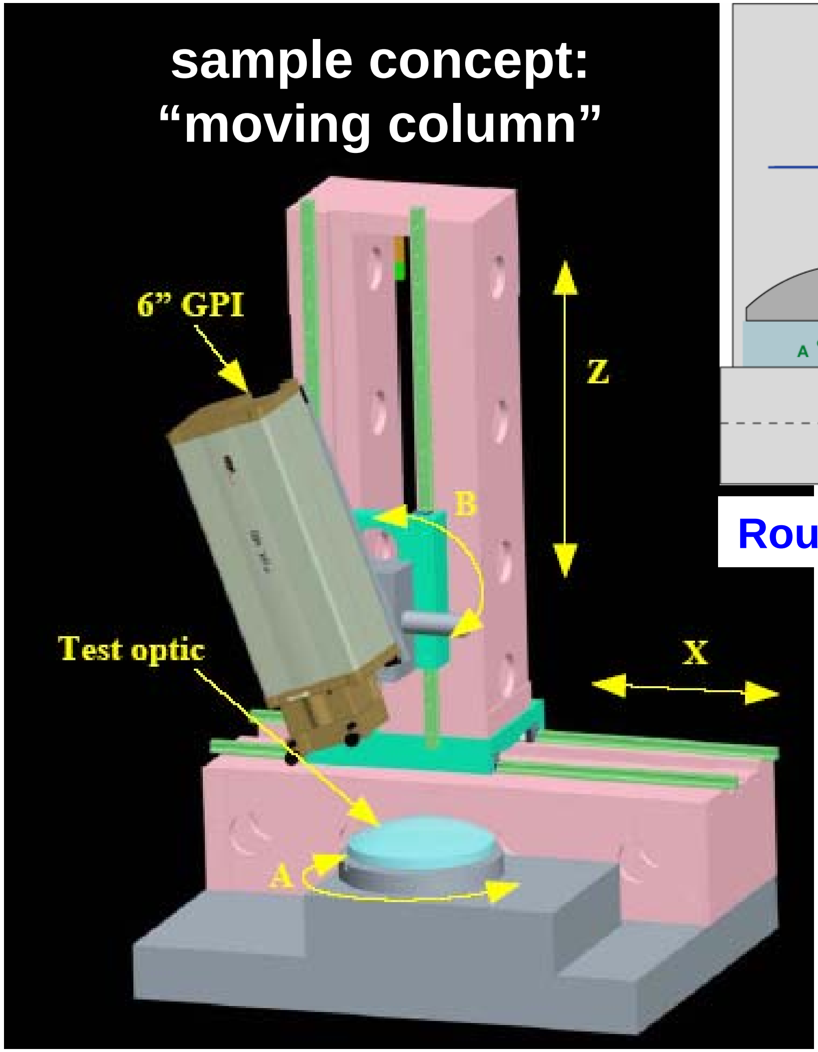


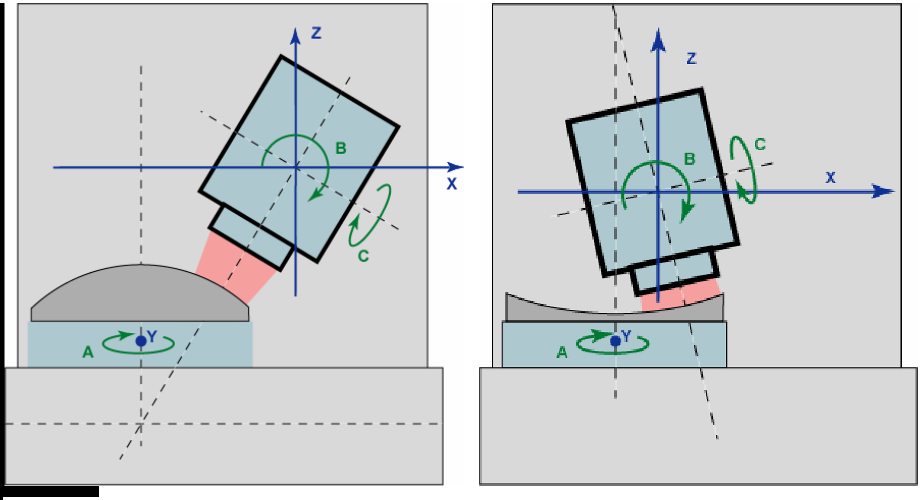
Larger optics: scaling the SSI®

- Larger parts have slightly different requirements
  - Mechanical distortion of the surface increases with part size
  - Moving (particularly tilting) the part is not desirable
  - Part takes a longer time to thermally stabilize
  - Transmission and nulling optics are not easy to scale up
- Stitching appears extensible to larger optics
  - The workstation needs some changes
    - Increased size and larger X travel
    - Tilt the interferometer, not the part
  - Using a 6” interferometer mainframe is preferred
    - A larger system adds considerable cost!
    - Larger mainframe = harder to move
    - Custom transmission spheres = long lead times

See Mirror Tech Days 2005 presentation on stitching:
http://optics.nasa.gov/tech_days/tech_days_2005/index.html

Larger platform concept

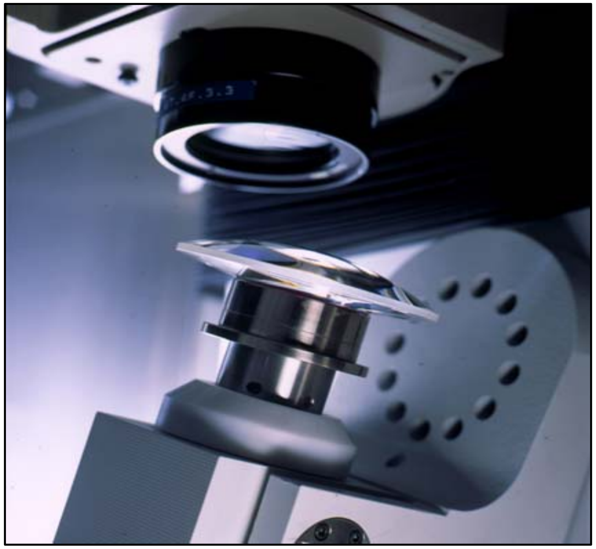


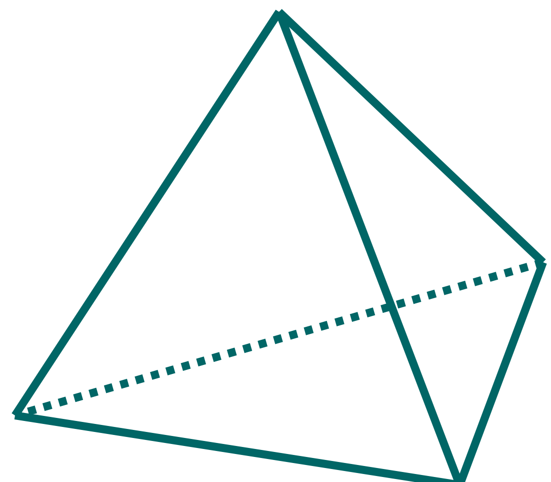


Rough schematics of tilting interferometer

Stitching technology is scalable to larger optics in both vertical and horizontal configurations.

Stitching Redefines the Boundaries





Conclusion:

Stitching boosts all these… but we'll always want more.

Subaperture stitching interferometry for advanced metrology solutions

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